LOS ALAMOS
ENERGY SECURITY

Winter 2006 Vol. 2, No.1

CO_2 molecules

Los Alamos NATIONAL LABORATORY EST.1943

The Carbon Sequestration Issue

INSIDE THIS ISSUE

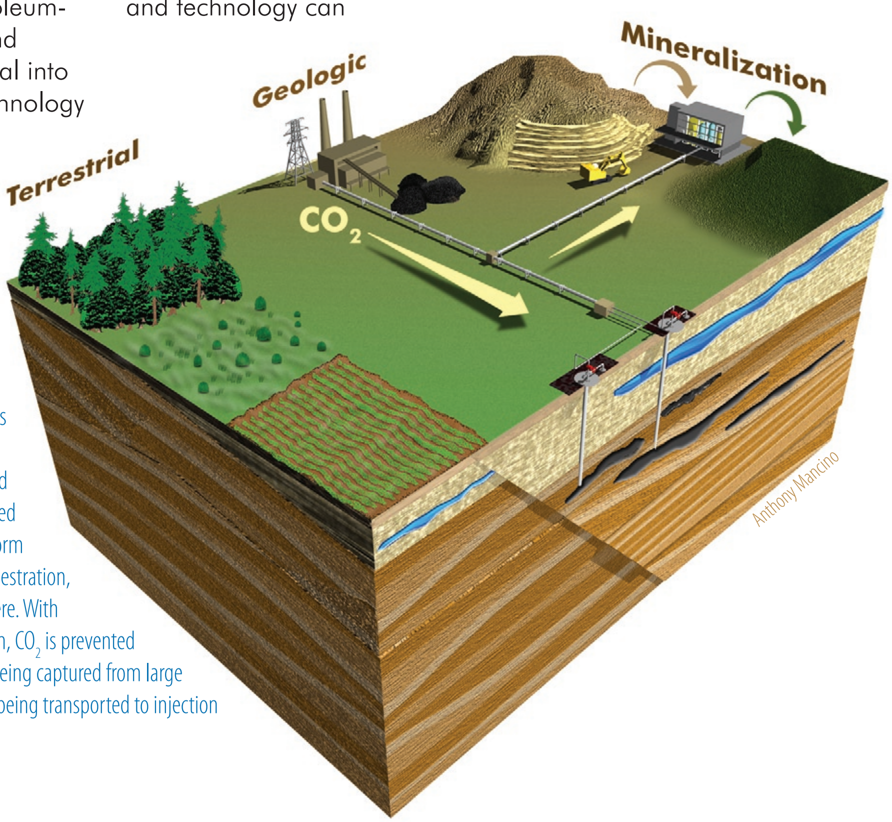
Regular Features

energysecurity.lanl.gov

Carbon-based fossil fuels, which account for ~65% of electricity production and ~86% of global energy consumption, drive the world's economy. With large global reserves, favorable economics, and an extensive technology and infrastructure base, these fuels are projected to play a central role in energy production for at least the next few decades. The Energy Information Administration's *Annual Energy Outlook 2006* projects continual growth in fossil fuel consumption through 2030 (see page 16 for a link to the report).

After 100 years of petroleum-based transportation and 120 years of turning coal into electricity, fossil fuel technology is mature. Technological advances over the past century have improved efficiency and lessened environmental impacts, but we now face the convergence of several challenges that demand radically new technologies. As population and economies around the world grow, projected increases in energy demand are staggering. Global energy consumption grew by 137 quadrillion BTUs between 1983 and 2002 and is expected to increase by another 233 quadrillion BTUs between 2002 and 2025. This dramatic increase poses challenges that science and technology can help meet. First, the limited supply of conventional oil and gas and the desire for energy independence have led to a reconsideration of unconventional fossil fuel resources, such as oil sands and shales, but these will require new extraction technologies. Second, technologies that increase efficiency in fossil fuel use, such as superconductivity and fuel decarbonization with concurrent hydrogen production can help extend supplies. And third, the potential impact of human activity on climate has led to global interest in capturing

continued on page 3



Los Alamos is working on three land-based sequestration methods: (1) terrestrial (enhanced carbon uptake by biological systems); (2) engineered geologic (storing carbon in depleted oil and gas wells and deep saline aquifers); and (3) mineralization (a concept pioneered at Los Alamos in which CO_2 is reacted with magnesium-rich silicates to form a stable solid). With terrestrial sequestration, CO_2 is absorbed from the atmosphere. With geologic storage and mineralization, CO_2 is prevented from entering the atmosphere by being captured from large emitters, like power plants, before being transported to injection sites or conversion facilities.

Los Alamos Energy Security, produced by Los Alamos National Laboratory's Office of Energy and Environment Initiatives, presents energy issues of critical national and global importance and highlights the Laboratory's research and development aimed at addressing those issues. For more information about Los Alamos National Laboratory's energy security research and development, go to **www.lanl.gov/energy**.

The current issue and back issues of this publication are available online at **energysecurity.lanl.gov**.

Editor/Writer/Graphic Designer
Anthony Mancino

Editorial Assistant
Ann Bustos-Gonzales

Printing Coordinator
Lupe Archuleta

Inquiries or subscription requests should be addressed to
energysecurity@lanl.gov, or
Energy Security Quarterly
c/o Anthony Mancino
Los Alamos National Laboratory
MS C331
Los Alamos, NM 87545

LALP-06-044

Knowledge and Innovation: Keys to a Bright Energy Future

Charryl Berger
Program Director, Office of Energy and Environment Initiatives
Los Alamos National Laboratory

Energy is all the buzz these days and a lot of it is anxiety inducing. We hear about rising oil and natural gas prices, increasing reliance on imported oil, increasing costs for residential heating and cooling, and the growing concern about global warming and its impact. These concerns are real and global in nature. But from where I stand, I see reasons for optimism. Things will change for the better, and science and technology will drive that change. Look at the oil and gas industry over the past two decades. Technology has had a tremendous impact on improving oil and gas production through advances in 3- and 4-D seismic imagery, advanced computing, subsalt imaging, remote sensing, directional drilling, tertiary recovery using carbon dioxide, and engineering advances in offshore wells. In the North Sea, production in the year 2000 was ten times higher than forecast in 1983 mainly due to these types of technological advances. Lester Thurow, former Dean of the MIT Sloan School of Management, summarizes it neatly: "The oil industry still produces oil, but it has been infused by so many new technologies that it should be thought of as one of the new man-made, brainpower industries like biotechnology."

The oil patch is not the only area in the energy field that will feel the impact of science and technology. As we continue to move into the future where more and cleaner energy is required, technological advances will make nuclear energy, zero emissions coal, hydrogen generation and storage, fuel cells, superconductivity, unconventional fossil resources such as oil shale, and a host of renewable options economically competitive, reliable, and environmentally sound.

Knowledge and innovation are becoming the critical resources for the energy business. Los Alamos is rich in that resource and already contributing significantly. We look around the Lab and see our national leadership in the diverse areas of low-temperature fuel cell technology, chemical hydrogen storage, and high-temperature superconductivity. More recently, Los Alamos has stepped out into new areas with huge potential impact. We are providing new ways of thinking about the scientific basis for ensuring permanent storage of carbon dioxide in engineered geologic systems. We have recently signed a strategic alliance agreement with Chevron to develop new approaches to *in situ* recovery of oil shale that make it both economically feasible and environmentally friendly. And we are developing new ways to separate and capture flue gases from power generators in order to decrease the environmental impact of fossil fuel combustion.

Energy security, which is critical to our economic and national security, is attainable with wise investments in research and development. The nation's valuable scientific and technological resources, like Los Alamos National Laboratory, are key to ensuring a sustainable energy future.

The Carbon Sequestration Issue

continued from page 1

and storing, or "sequestering," carbon dioxide so it does not enter the atmosphere. This last challenge is the subject of this issue of *Los Alamos Energy Security*.

The task of capturing and storing CO_2 is particularly formidable given the scale at which humans currently produce it—over 25 billion metric tons per year globally. To develop a suite of land-based options, spanning from terrestrial sequestration to geologic storage to innovative concepts like CO_2 mineralization, Los Alamos National Laboratory is applying some of its core scientific capabilities, such as

- ***Materials science***, especially gas separations (see page 10) and the behavior of geomaterials, like cement, under extreme conditions (see page 7).
- ***Scientific prediction and modeling***, essential ingredients in so many of the Laboratory's projects, are being directly applied to the carbon challenge through CO_2-PENS (Predicting Engineered Natural Systems), a conceptual framework that has now become a working computer model. CO_2-PENS combines theory, experiment, observation, and computation to predict the response of earth materials to the dynamic coupling of fluid flow, chemical reaction, and mechanical response (see page 6).
- ***Advanced sensors, monitoring approaches, and analytical methods*** to characterize and understand the complexities and processes in both terrestrial and geologic systems (see page 11).
- ***Risk analysis and safeguards*** which are being applied to CO_2-PENS to provide a comprehensive risk assessment of geologic CO_2 storage (see page 6).

With a significant institutional investment, Los Alamos has developed a broad base of research associated with the fate of CO_2 in geologic systems. This base now spans from experimental work on the behavior of supercritical CO_2 and subsequent geochemical reactions to advanced computational efforts to field observations. Los Alamos and its partners (including Sandia National Laboratories) conducted the first US field test of geologic CO_2 storage at Hobbs, New Mexico. We've also partnered with Kinder Morgan CO_2 to understand the long-term fate of wellbore cement—a potential weak spot in engineered geologic systems. Our investigation of grout samples recovered from one wellbore exposed to CO_2 and brine for 30 years provided the first direct data on cement-CO_2 interactions in natural systems (see pages 6 & 7).

While the focus in this issue is on carbon sequestration, the work presented here is part of a larger effort to address all parts of the carbon fuel cycle, including fuel extraction and use. Los Alamos's experience in fossil fuel extraction has grown over 25 years from early work in oil-shale utilization and reservoir modeling to more recent work in advanced seismic imaging and new monitoring and sensing approaches, such as our recent success with INFICOMM, a technology initially developed for covert communications that is now used by Chevron to retrieve data from deep oil and gas wells. Los Alamos is now using this experience to help an industrial partner develop innovative solutions to oil shale extraction. To find more efficient and less polluting ways to use fossil fuels, Los Alamos has done extensive research and development in fuel cells and hydrogen storage, which are integral to fuel decarbonization. In addition, Los Alamos is a world leader in the development of superconducting materials, which will significantly increase the efficiency of our electricity distribution infrastructure. Advanced, clean methods of producing power from hydrocarbon fossil fuels require separation of the energy carrier

Los Alamos National Laboratory and partners conducted the first US field tests of geologic CO_2 storage at Hobbs, NM (photo by Henry Westrich, Sandia National Laboratories).

(hydrogen) from the carbon by-products. Los Alamos is working on a number of innovative separation approaches, ranging from polymer membranes that are stable at high temperatures to the formation of tailored clathrates/hydrates. In addition to providing purified hydrogen fuel, these separation techniques prepare the carbon dioxide for long-term storage. Los Alamos is also assessing various strategies for improving the efficiency of fossil fuel utilization, including plasma catalysis.

While the ultimate goal may be to replace fossil fuels, no competing alternative is ready to take over their huge share of the global energy market. To sustain a high standard of living and extend that same standard to developing countries, we must use every scientific means at our disposal to mitigate the environmental effects of fossil fuel use over the coming decades. Los Alamos National Laboratory's efforts to do just that reflect the scientific spirit that gave birth to the Laboratory: theory and innovation can overcome seemingly insurmountable challenges.

— *George Guthrie*

Geology Summer Schools

Training the next generation of carbon sequestration professionals

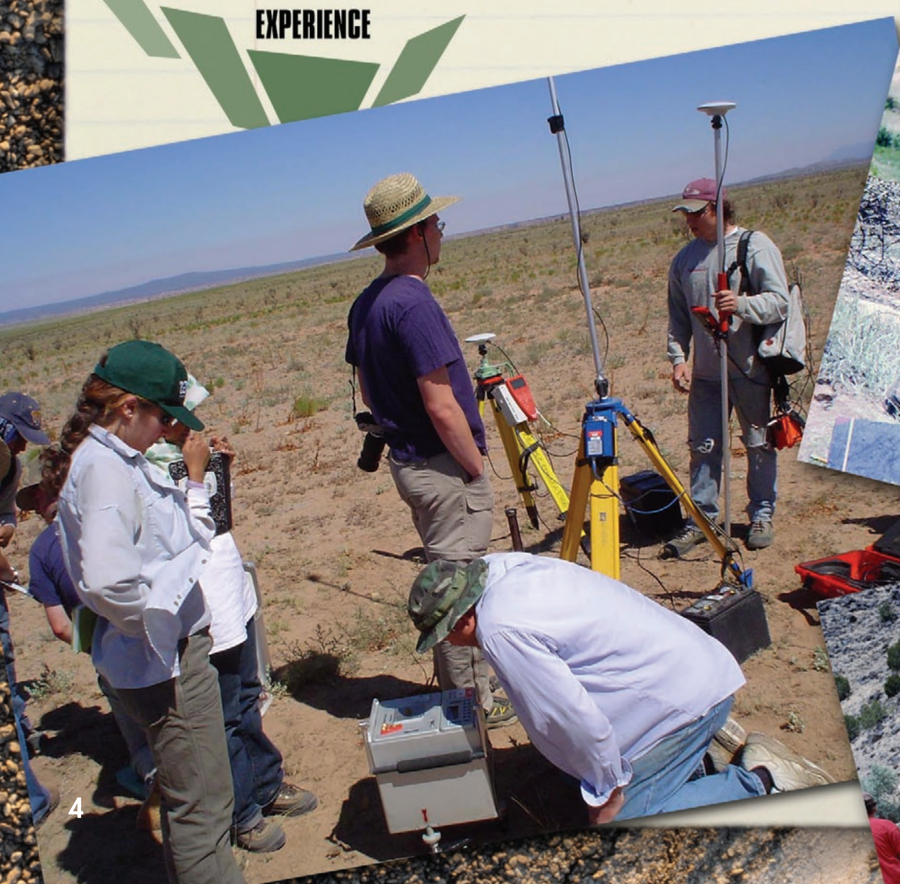
At a time when nearly all indicators of scientific and engineering dominance (e.g., patents, publications, new PhD's, and citations) show the US losing its competitive edge, Los Alamos National Laboratory recognizes that energy security and economic competitiveness are intertwined and both rely on educating and maintaining a sound scientific workforce. To help keep the US at the forefront of carbon sequestration science and engineering, and the underpinning geophysics, Los Alamos has been conducting education programs to recruit and train early career professionals in related fields.

Choosing a scientific or engineering field is easier if you can get outside the classroom and experience what specialists do firsthand. Giving students that opportunity is the goal of two Los Alamos-hosted summer geology education programs, RECS and SAGE.

SAGE (Summer of Applied Geophysical Experience) has operated in the Rio Grande rift in New Mexico since 1983. SAGE promotes careers in geophysics by introducing students to hands-on exploration and research. Students, US and foreign, are predominantly upper division or graduate students in geophysics or related disciplines or professionals from various earth science fields. Students combine geophysical data, acquired using a variety of techniques, with knowledge of the geological setting to derive integrated subsurface interpretations. These data are processed and modeled using state-of-the-art software. Various academic institutions and industrial affiliates provide modern field equipment and vehicles. The SAGE faculty consists of active and experienced researchers.

RECS (Research Experience in Carbon Sequestration) is a newer effort sponsored by the Department of Energy and conducted over the past two years. RECS focuses on the scientific and engineering challenges specific to geologic carbon sequestration. Unlike geophysics, carbon sequestration is not a well-defined

SUMMER of
APPLIED GEOPHYSICAL
EXPERIENCE



RECS 6 12.01 RESEARCH EXPERIENCE in CARBON SEQUESTRATION

discipline and involves students from many fields, including geophysics, geology, geochemistry, chemistry, biogeochemistry, atmospheric chemistry, engineering, economics, and law. The program was designed to help young researchers and professionals in diverse fields to network and establish a foundation for US academic, scientific, and technical excellence in carbon sequestration.

The RECS curriculum is aligned with the three pillars of the Department of Energy's Carbon Sequestration Program: (1) separation/capture, (2) long-term storage, and (3) monitoring/mitigation. Twenty graduate students from the US, Canada, and Mexico attended the two-week program in July of 2005, which took place at the College of Santa Fe, NM, and at the Kinder Morgan oil field (SACROC) in Snyder, Texas. Experts from industry, academia, and national laboratories provided presentations and lectures. The program also included hands-on fieldwork, demonstrations, and student presentations.

Los Alamos National Laboratory and EnTech Strategies, LLC, a Washington, DC-based carbon sequestration consulting firm, hosted RECS. The RECS program was a follow-up to 2004's US-Norway summer program on carbon capture and geologic storage—a collaboration between the National Energy Technology Laboratory, DOE's Office of Clean Energy Collaboration, and the Norwegian Research Council—which was also hosted by Los Alamos National Laboratory. SAGE is sponsored by the Los Alamos National Laboratory branch of University of California's Institute of Geophysics and Planetary Physics.

Learn more at http://www.ees1.lanl.gov/SAGE and http://www.recs.lanl.gov.

— *Melissa Miller, Scott Baldridge, and Anthony Mancino*

SAGE students gather geophysical data and conduct a seismic survey using a Vibroseis truck provided by Veritas DGC, Inc. (Left). RECS students examine core samples, collect field data, and gather around a CO_2 injection well at Kinder Morgan's SACROC site in Snyder, Texas (Right) . (RECS photos by Melissa Miller)

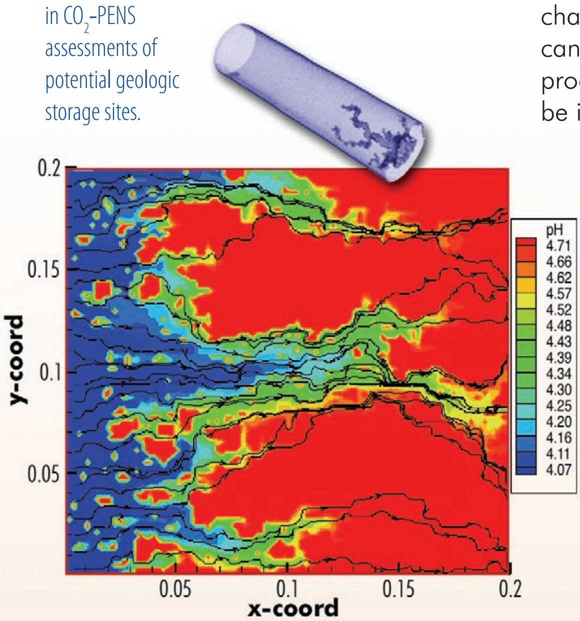
CO_2 PENS

PREDICTING ENGINEERED NATURAL SYSTEMS

A conceptual and computer model for ensuring safe and effective containment of CO_2

Geologic formations provide good repositories for CO_2 emissions, but with gigatons of CO_2 to manage, how will we find enough underground sites that are economical and safe for hundreds of years? Los Alamos researchers believe the answer is to develop a robust system-level model that tracks CO_2 from capture through injection and storage while predicting the likelihood of leakage to the surface. This system-level model must calculate risk to humans and the environment as well as economic impacts.

Wormholes can occur when CO_2 dissolves rock. The images below, generated by neutron tomography (top) and a numerical simulation (bottom), show wormholes in limestone created by a CO_2 reaction. This reaction, and the possible opening of new pathways, will be included in CO_2-PENS assessments of potential geologic storage sites.

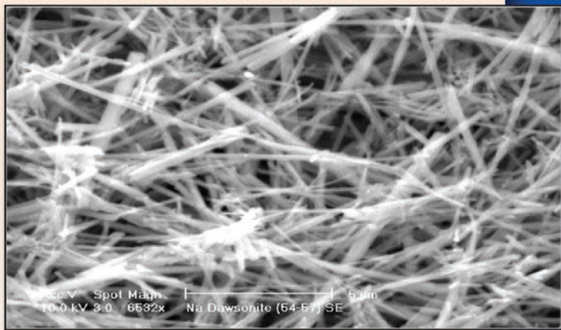


Los Alamos researchers have developed "CO_2-PENS," the first conceptual and computer model designed to integrate a host of CO_2 related components including CO_2 transport pathways, economics, risk analysis, existing knowledge from the oil industry, and innovative fundamental science.

CO_2-PENS is designed to adapt to changes in understanding. The model can be modified quickly to add new processes and interactions which can be identified by use of the system model itself, through expert elicitation, and through independent investigations undertaken to support the decision making process. The highest level of CO_2-PENS is used to manage global variables such as time, CO_2 mass balance, total risk, well statistics, and costs. These high-level variables are then passed into subprograms that can be modified or replaced by anyone working on the system model. This flexibility will allow CO_2-PENS to initially become a primary screening tool that can help users quickly decide on the applicability of sequestration sites. As site selection proceeds, CO_2-PENS can be modified for individual sites as detailed site-specific information becomes available. It is important to have a consistent platform for calculations of performance and risk across different sites to provide meaningful comparisons.

We have identified several key processes that require the input of fundamental science to predict site performance over long time periods for a variety of geologic settings. These include CO_2 flow in the subsurface, release of CO_2 through wellbores to the environment, chemical reactions involving CO_2 that can create or dissolve rock, and atmospheric CO_2 concentrations that result from leakage.

CO_2 forms an acidic solution that can dissolve rock and create new pathways. These pathways can enhance the ability of CO_2 to move through the subsurface. Existing models of oil reservoirs do not include this process. The figure to the left shows a neutron tomographic



Our numerical models predicted that dawsonite, a sodium aluminum carbonate, would form in a geologic reservoir injected with CO_2. The image above shows the successful laboratory synthesis of dawsonite in a CO_2-rich solution. The possibility of CO_2 becoming a stable solid under certain reservoir conditions is highly significant for long-term storage.

image and a numerical simulation of preferential path formation due to dissolution of limestone rock. As this research develops, we will incorporate new information on preferential pathways into the CO_2-PENS model.

Leakage through cement-plugged wellbores is currently considered a possible primary pathway for CO_2 flow to the surface (see sidebar at right). We are working with our industrial partner, Kinder Morgan, to obtain the first field samples of wellbores that have been exposed to CO_2 for 30 years. Because

continued on page 13

Resembling an archaeological artifact, the core sample below shows how cement has reacted over a long period of time (>30 years) in the presence of injected CO_2. Based on data gathered from the core, computer models can make the leap to centuries to predict how geologic storage sites will hold up over long periods of time. An orange, carbonated zone on a polished piece of the core (right) shows how CO_2 has affected the cement. The core sample was extracted from the Kinder Morgan Company's SACROC site in Snyder, Texas, where naturally occurring CO_2 has been injected for over 30 years to enhance oil recovery.

HOW WILL CO_2 AFFECT GEOMATERIALS?

The feasibility of geologic sequestration depends critically on how CO_2 interacts with the geomaterials that comprise the reservoir storing the CO_2 and the cap rock that prevents its escape. An ideal reservoir would have a stable cap rock that is impervious to the buoyant flow of CO_2 and a reservoir that will allow CO_2 to react with brine and minerals to gradually transform the mobile gas into dissolved carbonate species and ultimately into immobile solid mineral carbonates.

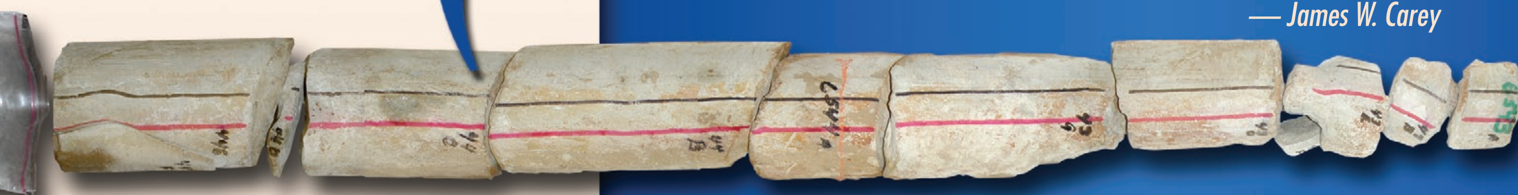
A geologic sequestration site includes injection wells and, most likely, pre-existing oil and gas production wells that perforate the cap rock creating potential pathways for CO_2 to escape from the reservoir (see next page). A variety of Portland cement, which reacts with CO_2, is used to seal most abandoned wellbores. Our studies include experimental and numerical investigations of cement-CO_2 reactions and field studies of old wellbore systems with long (30-year) histories of CO_2 exposure caused by enhanced oil recovery operations. These studies have provided observations of chemical changes in the wellbore system. The image below shows a polished section of cement recovered from the SACROC field in West Texas (obtained through our collaboration with Kinder Morgan CO_2 Co.) that shows the effects of CO_2 in an orange carbonated zone adjacent to the cap rock.

The cap rock's thickness and impermeability allow oil and gas deposits and aquifers to exist and their existence proves that natural systems can trap buoyant fluids for geologic periods of time. But fractures and faults present potential limitations to cap rock integrity. Because large faults are readily identified with geophysical techniques, much of our work has focused on determining whether fractures seal themselves or widen with the flow of CO_2. The geologic record shows many examples of carbonate-sealed fractures, and we are studying the tendency of shale fractures to precipitate calcite and other carbonates. Since many shales consist of clay minerals that swell and shrink in response to changes in water availability, we are studying the possibility that a CO_2 plume could dehydrate clays and permit flow along fractures.

In contrast, the reactivity of reservoir materials could also allow injected CO_2 to transform into a much less mobile form halting flow altogether. The injected CO_2 could react with minerals in the reservoir to precipitate carbonate minerals (i.e., turn into solid rock). This possibility offers the most permanent form of CO_2 storage. Many of our numerical models predict that the sodium aluminum carbonate, dawsonite, may form in geologic reservoirs. We are studying the solubility and precipitation kinetics of this mineral to quantify this important trapping mechanism.

Understanding the chemical reactions that occur between materials in a CO_2 storage system and the varying time scales for those reactions is critical to demonstrating the long-term safety and effectiveness of geologic CO_2 storage.

— James W. Carey



The Geologic Carbon Storage System

1 The process of storing CO_2 underground begins with a large emitter, such as a coal-fired power plant. Unlike automobiles, with their widely distributed emissions, power plants and other industrial sites provide centralized points where large concentrations of CO_2 can be captured.

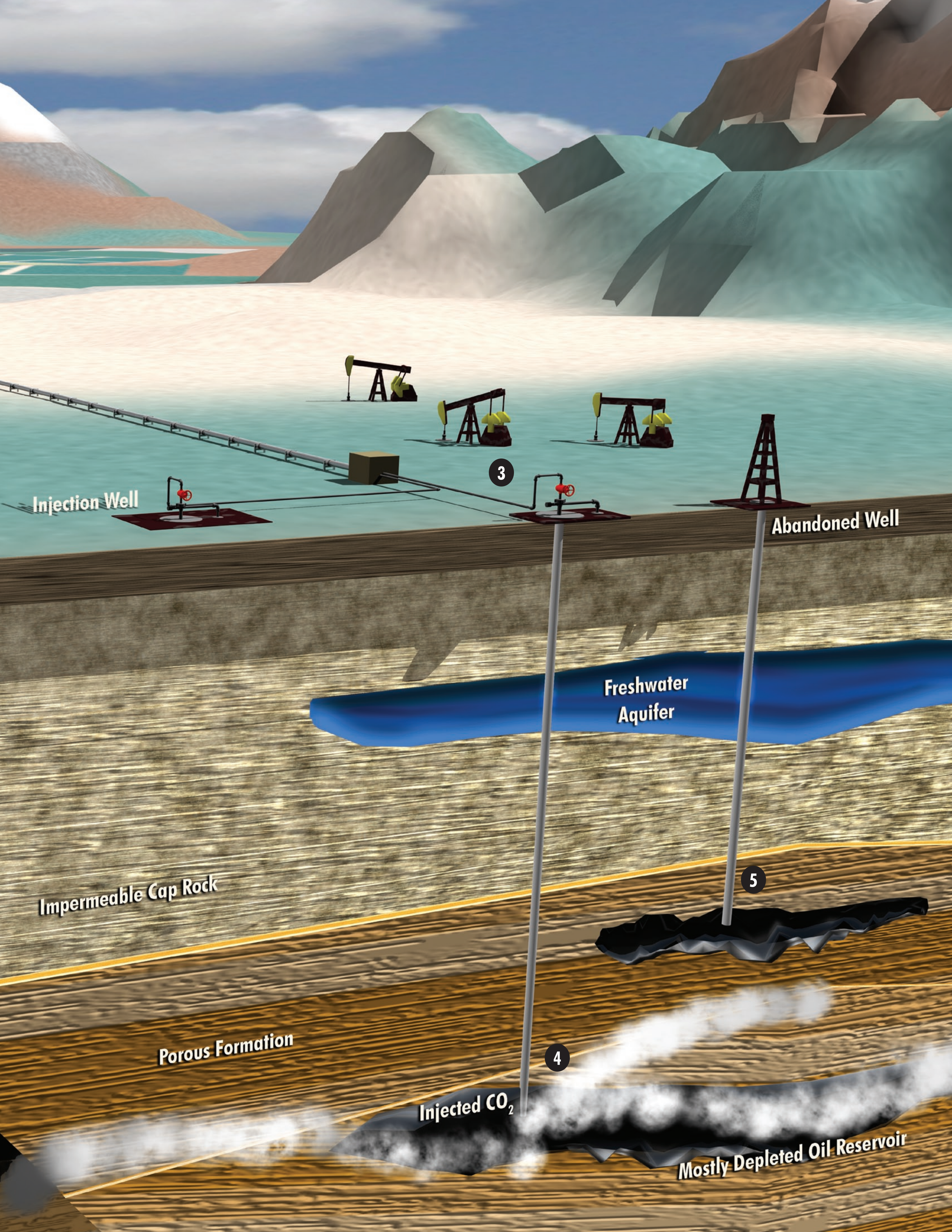
2 Before CO_2 can be transported to a geologic repository, it must be separated from a mixed gas stream. In a conventional coal plant (represented here), the CO_2 is removed from the combustion exhaust. In an advanced Integrated Gasification Combined-Cycle (IGCC) process, hydrogen and carbon are separated from the fossil fuel prior to combustion. The hydrogen is used as a fuel, and the carbon is sent to a long-term storage repository (see page 10 for more on separation and capture).

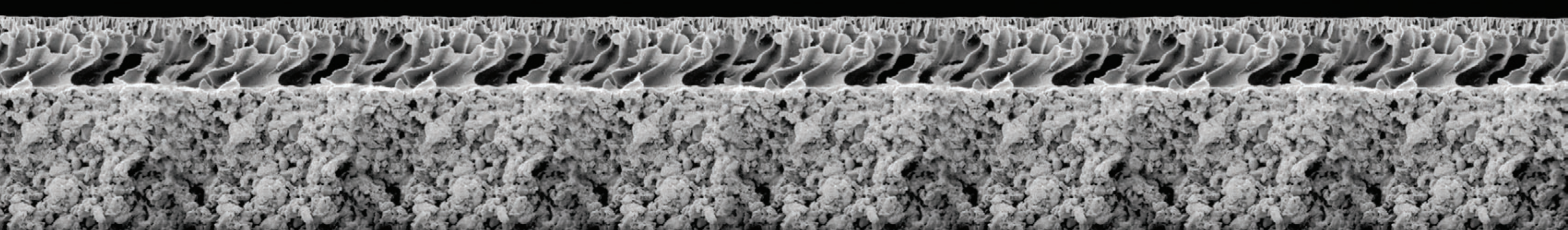
3 The captured CO_2 is transported to an injection site, in this case via pipeline to a mostly depleted oil field. Oil and gas reservoirs have already demonstrated their ability to contain gases and liquids over geologic time scales.

4 The CO_2 is injected into the mostly depleted oil reservoir and also travels into the surrounding porous formation that is saturated with brine.

5 Millions of abandoned well shafts present possible escape routes for injected CO_2. When CO_2 mixes with brine in the formation, it forms an acidic compound that can erode geomaterials, such as the cement used to plug old wells. In contrast, CO_2 can also react with the formation to create new minerals that block flow. Understanding and predicting these geochemical reactions is critical to effective long-term storage (see pages 6 and 7).

6 While the impermeable cap rock would prevent catastrophic release, the CO_2 is buoyant and could possibly travel up along faults or migrate far from the injection site until it finds an escape path. Accurate characterization of the geology, advanced monitoring technologies, and predictive modeling is critical to safe and effective CO_2 sequestration (see page 6).


3
Injection Well
Abandoned Well
Freshwater
Aquifer
5
Impermeable Cap Rock
Porous Formation
4
Injected CO_2
Mostly Depleted Oil Reservoir



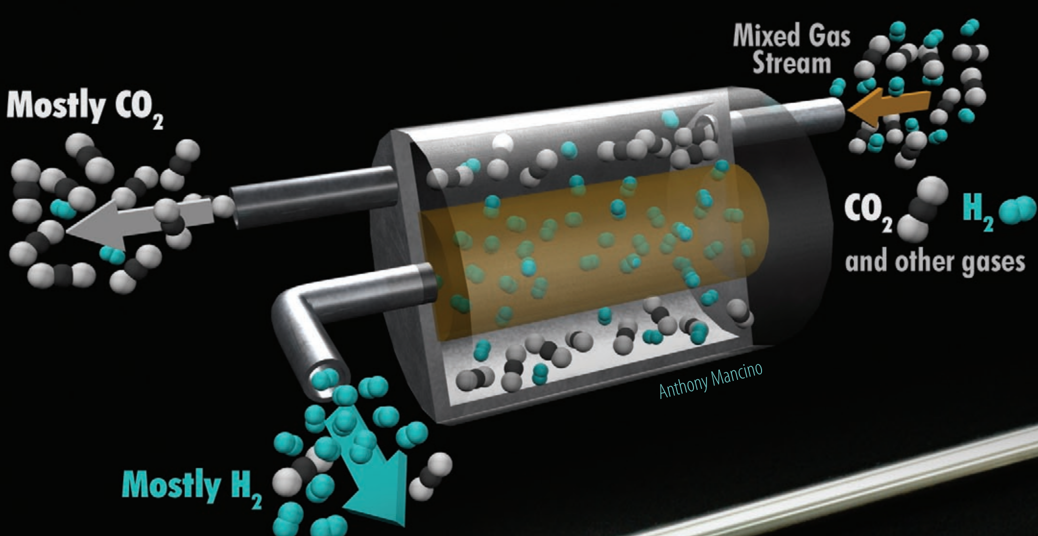
THERMALLY OPTIMIZED MEMBRANES for Separation and Capture of CO_2

Separating and capturing carbon dioxide from mixed gas streams is a first and critical step in carbon sequestration. Los Alamos National Laboratory and its partners are addressing this challenge with a number of unique and innovative approaches including polymeric-metallic composite membranes, CO_2 hydrates, acoustic phase separations, composite metal membranes, porous ceramic membranes, and hybrid separation materials. The Laboratory's work in the first of these, polymeric-metallic composite membranes, has recently made significant strides toward demonstrating the technical and economic feasibility of capturing CO_2 from large point sources, such as power plants. In collaboration with Pall Corporation, University of Colorado, and Idaho National Laboratory, Los Alamos Principal Investigator Kathryn A. Berchtold is developing polybenzimidazole (PBI)-based polymeric-metallic composite membranes that can purify hydrogen and capture carbon at high temperatures. The work focuses on a pre-combustion capture approach that integrates the high-temperature polymeric-metallic composite membranes into an advanced Integrated Gasification Combined-Cycle (IGCC) process (as opposed to a post-combustion approach aimed at separating CO_2 from the exhaust stream of a conventional power plant burning fossil fuels).

The project's primary goal is to develop polymeric-metallic composite membrane structures that achieve the critical combination of high selectivity, high permeability, chemical stability, and mechanical stability at elevated temperatures (>150 °C). Stability requirements are focused on tolerance to the primary synthesis gas components and impurities at various locations in the process. Because temperature and pressure conditions and the composition of the gas stream vary throughout IGCC power production, the project has focused on modeling and evaluating membrane performance at several different points along the process to ensure deployment at the optimal location.

The research team is pursuing two major pathways to its primary goal. The first involves extending the current PBI-based polymeric-metallic composite membrane to its limits. To achieve this, much effort is being placed on membrane productivity optimization, module design, in-lab and out-of-lab testing of optimized composite membranes and modules, systems integration, and economic analysis. The second pathway is aimed at developing and synthesizing new PBI-based compounds that improve the base PBI material used in the first pathway. By

continued on page 13



This simplified model of the single tube membrane module shows a mixed gas stream (composed of hydrogen, CO_2, and other gases) entering the outer tube. The membrane blocks most of the CO_2 but allows hydrogen to pass through to the inner chamber where it can be collected and used as fuel. The separated carbon-rich stream exits the outer tube at high pressure, ready for transport to a carbon storage repository.

Polybenzimidazole-coated AccuSep® media tube, manufactured by Pall Corporation, with ~67 cm^2 of active membrane area (photo by Kathryn Berchtold). The SEM image across the top of the page shows a microscopic view of the polybenzimidazole-based polymeric-metallic membrane (courtesy of Pall Corporation).

Helping Nature Do Its Job

Measurement, monitoring, and verification for terrestrial sequestration

Each year, the natural biosphere absorbs a quantity of carbon equal to one third of human carbon emissions, and a significant portion of that carbon remains stored in the roots of plants and in soil. Enhancing this natural process of terrestrial carbon sequestration through accelerated plant growth, reclamation of degraded lands, and sound land use management provides a near-term option for reducing atmospheric CO_2 while researchers continue to develop engineered geologic carbon storage systems and carbon-free fuel technologies.

Market-based carbon credit trading programs have already been established to provide the industrial and agricultural communities an economic incentive to reduce emissions and/or engage in land management practices that enhance terrestrial sequestration (see web link to Chicago Climate Exchange on page 16). But trading carbon credits as a currency requires accurate, cost-effective quantification and verification of carbon in soil and the atmosphere, and this presents a formidable scientific and technical challenge. To respond to this challenge, the Department of Energy's Office of Fossil Energy asked Los Alamos National Laboratory to develop advanced measurement, monitoring, and verification (MMV) technologies. A few of these technologies are described below.

Laser Induced Breakdown Spectroscopy (LIBS)

One of the quickest and most accurate analytical tools Los Alamos has developed is Laser Induced Breakdown Spectroscopy (LIBS). LIBS is a universal detection technology that can identify most elements within a sample. The LIBS device focuses a laser on the sample to form a plasma containing electronically excited species from the sample surface. As these elements relax back to a ground state, they emit light that is characteristic of the elemental composition of the sample. Some of the emitted light is directed through a dispersive spectrometer, which identifies the elements by their unique spectral signatures. LIBS can analyze samples far more rapidly than conventional methods. Data collection takes 10 to 20 seconds and spectral analysis requires less than an hour for most

continued on next page

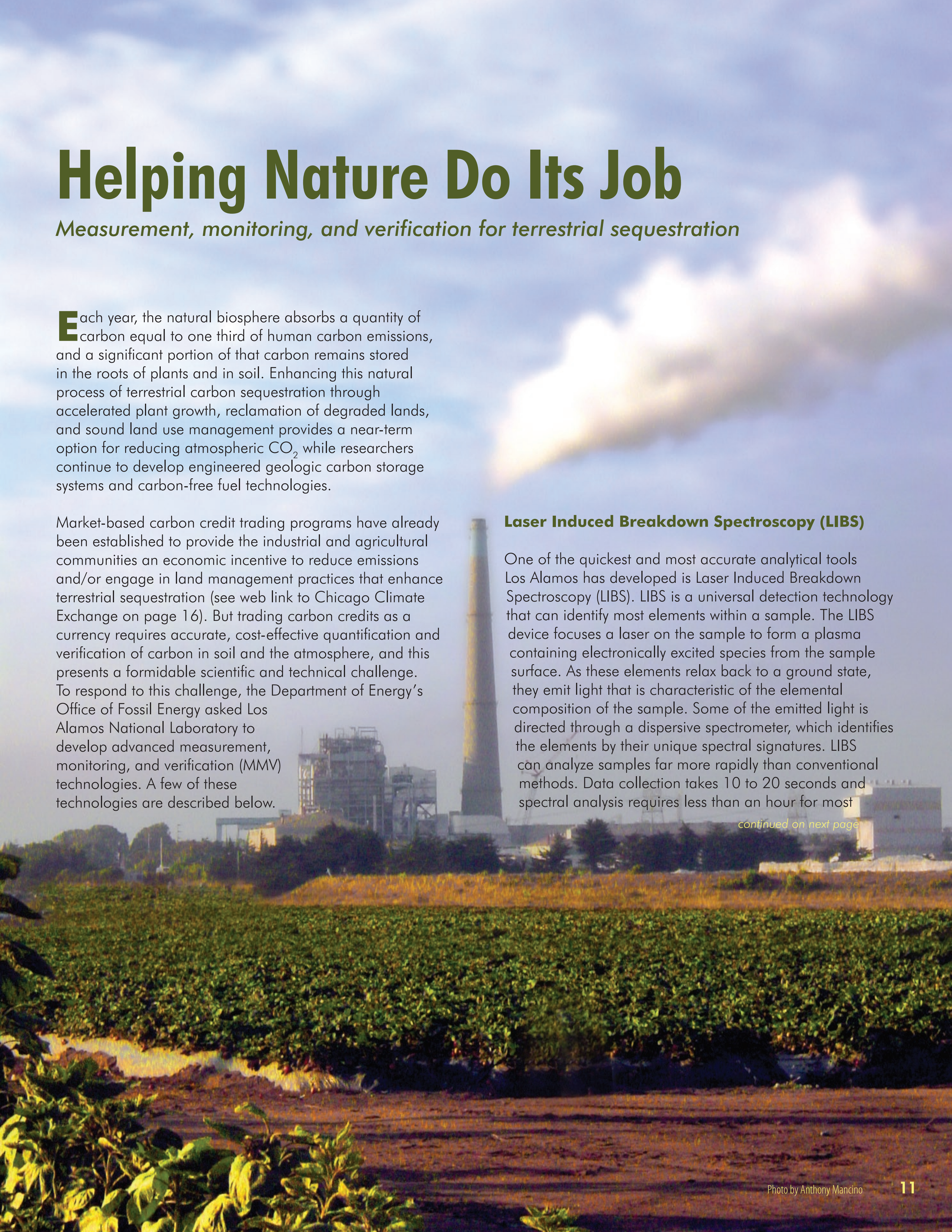
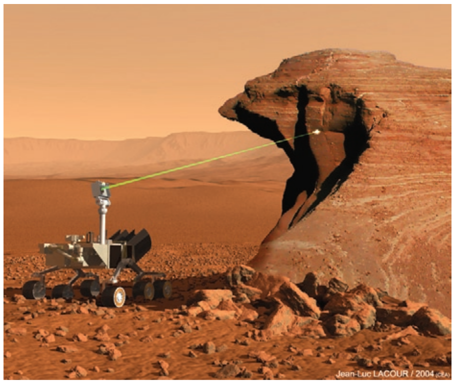


Photo by Anthony Mancino



The same Los Alamos LIBS technology that is being deployed on the Mars Rover to analyze samples is used on this planet to measure carbon in natural systems (image by Jean-Luc Lacour).

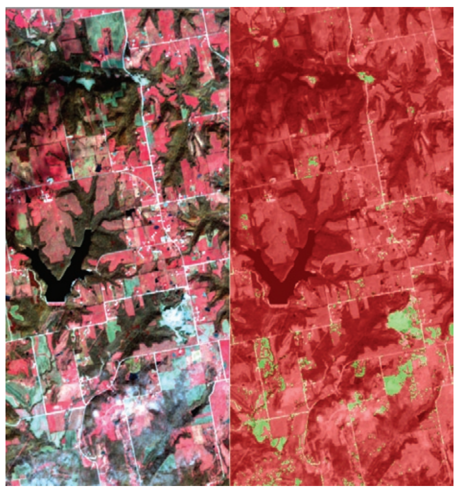
samples. Because LIBS is fast and readily adaptable to field-portable instrumentation, investigators can measure soil carbon in near real time, in remote locations, or in a laboratory where high-throughput analysis is possible. High spatial resolution, on the order of millimeters, is technically feasible with LIBS and could provide soil carbon concentration information not obtainable with standard methods. Its portability and analytical precision have made LIBS a critical component of MMV networks for carbon monitoring and soil science in general.

Raman Spectroscopy

Raman spectroscopy is complementary to visible, infrared, and LIBS analytical techniques because some components in soil that are "inactive" in visible and infrared regions are Raman "active." Raman spectroscopy is based on the inelastic scattering of light where frequency shifts of that light are attributed to changes in vibrational and rotational energy levels of molecules within the sample. Raman spectroscopy can distinguish between organic and inorganic carbon, which is crucial for assessing carbon stocks in terrestrial landscapes. Since a certain amount of carbon flux is always present in a natural system, the ability to measure organic and inorganic carbon separately allows investigators to determine how much carbon can be attributed to human-induced changes in land management. Inorganic carbon in soil will most likely be bound in the form of the carbonate anion (CO_3^{2-}), which has specific Raman active vibrations.

Regional Analysis of Soil Carbon Adaptive Learner (RASCAL)

The power of LIBS and Raman spectroscopy are greatly enhanced when combined with RASCAL, a software package based on Los Alamos's award-winning GENIE technology that plans where and how much to sample. Terrestrial systems, at any scale, are almost always heterogeneous. The different colors in the satellite photo below illustrate this heterogeneity. Without a planning tool like RASCAL, you could sample randomly and possibly miss the most



Out of several features, or "strata," visible in the aerial photo (left), RASCAL has picked out just the area with native prairie grass (green patches in right image). RASCAL can tell you where and how much to sample to accurately count carbon in that one strata. After proceeding in the same way for other strata, an accurate, complete assessment can be made.

important sites. Or you could lay a grid over a satellite map or a soil core and sample at regular intervals, but that's far too neat to capture the messy complexity of natural systems, and it may lead to a lot more sampling than is necessary. That gets expensive. However, users can teach RASCAL to identify any parameters (called "strata") that they wish (e.g., soil or vegetation type, or topographic features such as slopes or canyons, etc.). The program determines how much area belongs to each of these "strata" and helps plan how many samples should be taken and where they should be taken to get the most accurate analysis. Field sampling results can train RASCAL's machine learning engine and refine statistical strata for more efficient future sampling.

Stable Isotope Analysis and Eddy Covariance Systems

Los Alamos has also been measuring CO_2 flux at the land-atmosphere interface using eddy covariance towers and soil chamber systems. These techniques allow researchers to understand the impacts of land management and climate on terrestrial carbon sequestration and to detect leaks from underground CO_2 storage reservoirs in geological sequestration experiments. Combining flux with stable isotope analyses of CO_2, ecosystem health and productivity can be determined in terrestrial settings, and the origin of CO_2 (either biological or industrially stored) can be determined in geological settings. With the Laboratory's new stable isotope facility and multiple eddy covariance systems, rapid analyses of CO_2 flux and origin can be made across varying terrains at multiple scales.

Together, these technologies form an integrated suite of MMV tools that can provide the precise, reliable, and cost-effective analysis required to run a successful carbon emissions trading program.

— *Richard Benson, Sam Clegg, Pat Unkefer, Julianna Fessenden, and Anthony Mancino*

Eddy covariance tower and soil chamber system used to measure CO_2 flux at the Valles Caldera in New Mexico.

CO_2-PENS, continued from page 7

there is only a 30-year record, we are using numerical models to estimate reaction rates that will allow us to calculate leakage rates. These leakage models are being incorporated into CO_2-PENS.

In addition to dissolving rock, CO_2 can actually create rock (See sidebar and image on page 7). Understanding the conditions under which this occurs is very important for assessing potential sequestration sites because formation of minerals reduces the ability of CO_2 to flow and may reduce the ability of a well to accept injected CO_2. On the positive side, turning CO_2 into rock is the most permanent and stable form of storage possible.

CO_2-PENS is already proving useful in showing complex interactions between the different components of a CO_2 storage framework. The system model will provide a consistent standard for documenting decisions made during the site selection, implementation, and closure periods. Ultimately, we envision CO_2-PENS will become a primary tool used throughout the DOE complex, universities, and possibly industry to analyze potential CO_2 sequestration sites.

— *Philip Stauffer and Hari Viswanathan*

Thermally Optimized Membranes, continued from page 10

building upon the base PBI framework, new materials with enhanced gas separation properties (primarily H_2/CO_2 selectivity and H_2 flux) can be developed while desirable properties of the base material—such as chemical, mechanical, and thermal stability—are maintained. To support both pathways, the team has developed a unique methodology to understand, predict, and optimize the materials' mechanical and transport behavior over long periods of time and under challenging operating conditions.

The new composite membranes function at significantly higher temperatures (>400 °C) than currently available polymeric membranes (<150 °C). In addition, they provide improved performance while exhibiting long-term hydrothermal stability, sulfur tolerance, and overall durability over a broad range of industrially relevant operating conditions. This work supports the DOE Office of Fossil Energy/National Energy Technology Laboratory's and Los Alamos National Laboratory's Carbon Sequestration Program.

— *Kathryn A. Berchtold*

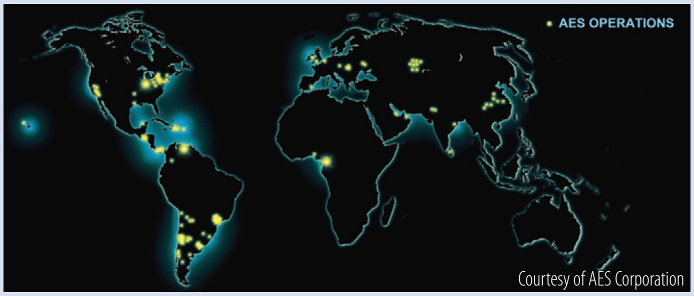
The Global Power Company

Los Alamos NATIONAL LABORATORY

WORKING WITH INDUSTRY

Los Alamos National Laboratory and AES Corporation Form Strategic Partnership

Los Alamos National Laboratory and AES Corporation have recently formalized a strategic partnership that will enable the two entities to identify, evaluate, and develop a range of mutually beneficial technologies that have broad energy applications. Headquartered in Arlington, Virginia, AES Corporation is one of the world's leading power companies, generating and distributing electric power in 26 countries through an array of world-class power businesses.



Courtesy of AES Corporation

Potential areas of collaboration include

- Greenhouse gas offset technologies
- Smart networks
- Technology grids
- Generation technologies (e.g., integrated gasification combined cycle, zero emission fossil fuel, renewable, closed-loop biomass, nuclear)
- Water technologies
- Energy storage
- Biofuels
- Operational reliability and efficiency
- Separation technologies
- Power-aware computing (e.g., "EnergyFit," see below)
- Fuel cell technologies

Los Alamos and AES have also executed an Exclusive License Option Agreement for a unique technology called "EnergyFit"—a transparent software layer that reduces the power consumption of high-performance computing systems. Because the algorithm minimizes the energy consumed by individual CPUs in a cluster, EnergyFit can dramatically reduce overall power consumption in a data center. EnergyFit delivers typical system energy savings of 10-25% with a bounded performance reduction of less than 5%. Energy consumption is the largest component of a typical data center's budget. EnergyFit's novel, patent-pending algorithm has been proven to yield the maximum energy savings while delivering computational results within a deadline.

Los Alamos and AES envision a long-term cooperative effort that will involve a variety of important and mutually beneficial energy-related projects.

Ning Li, 2006 Asian American Engineer of the year.

Los Alamos Nuclear Energy Scientist Named 2006 Asian American Engineer of the Year

Ning Li, a Los Alamos scientist recognized for his leadership in developing an important heavy-liquid metal nuclear coolant technology for advanced nuclear reactor and waste transmutation applications, has been named the 2006 Asian American Engineer of the Year by the Chinese Institute of Engineers USA (CIE/USA).

Ning Li has been honored for his outstanding scientific and technical achievements. He is the Laboratory's project and team leader for heavy liquid metal coolant technology and materials development in the Advanced Fuel Cycle Initiative program, the Generation IV Nuclear Energy Systems program, the Advanced Accelerator Applications program, and the Accelerator-Driven Transmutation of Waste project. He leads the design, construction, and operation of a fully instrumented large-scale lead-bismuth materials and thermal hydraulic loop (the Delta Loop) that is the only such test facility in the US and that serves as a versatile test bed for a variety of materials testing operations. He is also an adjunct professor in the Mechanical Engineering Department at the University of Nevada, Las Vegas, and a visiting scientist in the Nuclear Science and Engineering Department at MIT. He has authored 97 publications and technical reports and has received one patent.

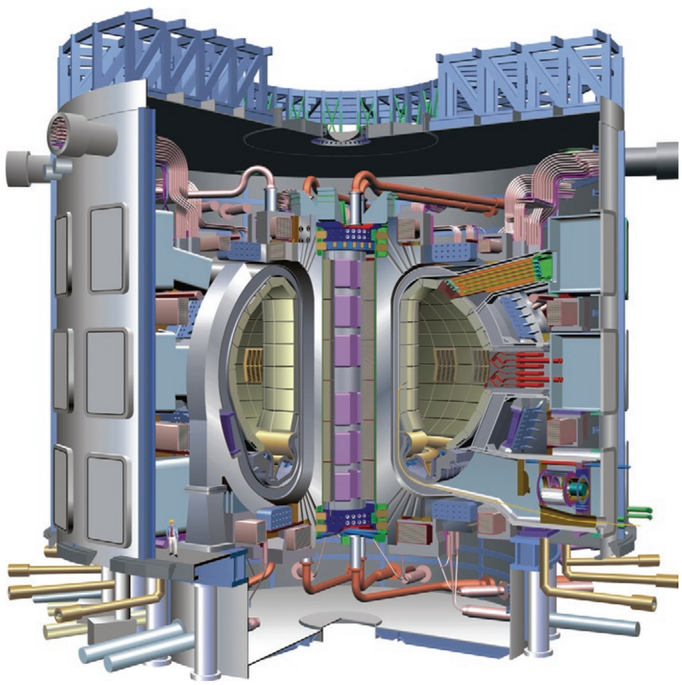
Originally from Hangzhou, People's Republic of China, Ning Li earned his bachelor's degree in physics from the University of Science and Technology of China, and his PhD at the University of California, Santa Barbara. He then pursued his interests in nonlinear fluid dynamics as a Los Alamos Postdoctoral Research Fellow. He currently works in the Condensed Matter and Thermal Physics Group (Materials Science and Technology Division).

The CIE/USA award recognizes established engineers who have made outstanding contributions to the engineering profession, the public welfare, and/or humankind. This is the fifth consecutive year that a Los Alamos scientist has received the award. The previous Los Alamos recipients are Quanxi Jia, Wu-chun Feng, Joe Tiee, and Paul Pan.

Los Alamos Participates in ITER, a Major International Fusion Project

While difficult to achieve, magnetically confined fusion would provide a limitless supply of energy with no greenhouse gas emissions and minimal proliferation and long-term waste issues. Present generation experiments have nearly managed to break even, (i.e., the fusion power generated equals the power required to run the machine). An international collaboration called ITER ("the way" in Latin) is presently finalizing an agreement to build a next-generation experiment designed to reach ten times the break even point or better. Partners include the US, Europe, Japan, South Korea, China, Russia, and India. The new reactor will be built in Cadarache in southern France. A number of tasks have been assigned to the US, including leadership for the Tokamak Exhaust Processing (TEP) system. On a given pass through the reactor only 5% or less of the deuterium-tritium fuel is consumed, so the Tritium Plant must clean up the reactor exhaust and prepare it for re-injection into the machine. Los Alamos has extensive experience in this area based on the Tritium Systems Test Assembly program (now decommissioned) and active participation in ITER Tritium Plant research since 1989. In support of ITER, Scott Willms and Craig Taylor of the Chemistry Division's Chemical Science and Engineering Group attended a Tritium Plant Working Group meeting in Daejeon, South Korea where tritium plant R&D, design, and construction plans were coordinated with counterparts from Germany, Japan, South Korea, and the ITER central organization. Willms, Taylor, and other Los Alamos personnel are currently preparing the TEP procurement plan.

Cutaway of the ITER Tokamak fusion reactor.



Los Alamos National Laboratory participated in the development of the nuclear space "battery" that will power NASA's New Horizons spacecraft (inset) on its journey to Pluto (courtesy of NASA).

DOE Labs Help NASA Seek "New Horizons"

On January 19, the New Horizons spacecraft began a 9½ year journey to Pluto and its moons. The spacecraft will receive heat and electricity from a long-lasting "space generator" developed and assembled by scientists and engineers at the Department of Energy's Los Alamos, Idaho, and Oak Ridge National Laboratories. This power technology provides an uninterrupted and reliable source of heat and electricity through radioactive decay of plutonium-238. Each laboratory played an integral role in the development, assembly and testing of the radioisotope thermoelectric generator or "RTG." Oak Ridge developed and fabricated the material used to encapsulate the plutonium; Los Alamos purified, pelletized into ceramic form, and encapsulated the plutonium; and Idaho National Laboratory assembled and tested the RTG and delivered it to the Kennedy Space Center.

"This is an amazing mission when you think about the time, distance, and harsh environment that the spacecraft will encounter," said Secretary of Energy Samuel Bodman. "Developing the technology to sustain the instruments in deep space over a long period of time required America's best and brightest minds."

New Horizons will cross the solar system in record time and conduct flyby studies of Pluto and its moon in 2015. For more information on the New Horizons mission, visit http://www.nasa.gov/mission_pages/newhorizons/main.

Los Alamos Fuel Cell Work Recognized

Four of Los Alamos's fuel cell efforts were among the Top Ten Research Accomplishments in 2005 recognized by the Freedom Cooperative Automotive Research (FreedomCAR) Fuel Cell Technology Team. In addition, two of the remaining selected accomplishments by Oak Ridge National Laboratory and Brookhaven National Laboratory are Los Alamos collaborations. FreedomCAR, established in 2003, is a public/private partnership between the US Department of Energy and the US Council for Automotive Research (USCAR) aimed at enabling a hydrogen transportation economy while preserving transportation freedoms. USCAR is an umbrella organization of DaimlerChrysler, Ford, and General Motors, which was formed in 1992 to further strengthen the technology base of the domestic auto industry through cooperative research. The four selected Los Alamos research accomplishments address the key barriers to commercialization of polymer electrolyte membrane (PEM) fuel cells, namely cost and durability.

Mobile Climate Monitoring Facility Moved to Niger

In the last issue, we reported that the Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) had been deployed in Point Reyes, CA. It has now been moved to Niamey, the capital of Niger, Africa. Operated and maintained by Los Alamos National Laboratory, the AMF will record data on clouds, aerosols, and water vapor in the atmosphere to improve global climate models. Because Niamey is in the middle of the Sahara Desert, the AMF will also record the impact of airborne Saharan dust, which can travel half way around the globe, on incoming solar radiation.

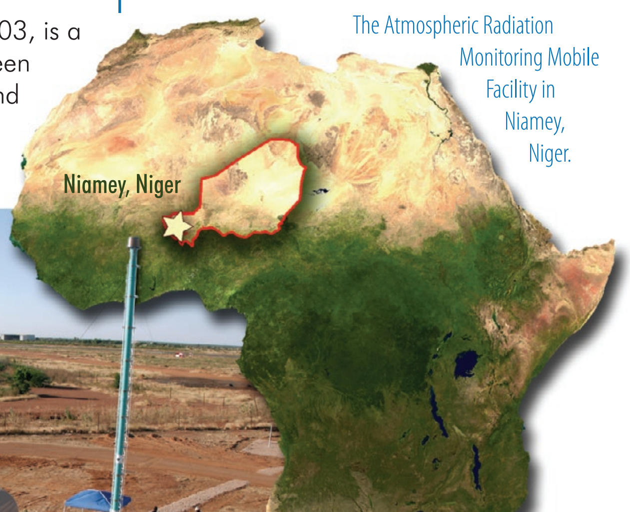


Photo by Kim Nitschke

The Atmospheric Radiation Monitoring Mobile Facility in Niamey, Niger.

ENERGY RESOURCES

Publications, events, and web sites for people interested in energy-related issues.

Publications

US DOE Carbon Sequestration Technology and Roadmap Plan 2005

http://www.fossil.energy.gov/programs/sequestration/publications/programplans/2005/sequestration_roadmap_2005.pdf

National Energy Technology Laboratory's Carbon Sequestration Newsletter

http://www.netl.doe.gov/publications/carbon_seq/subscribe.html (Free subscription and archives)

The Cost of US Forest-Based Carbon Sequestration (Pew Center)

http://www.pewclimate.org/global-warming-in-depth/all_reports/carbon_sequestration/index.cfm

Energy Information Administration Annual Energy Outlook 2006

http://www.eia.doe.gov/oiaf/aeo

Events

DOE's 5th Annual Conference on Carbon Capture and Sequestration
May 8-11, 2006
Alexandria, VA
http://www.carbonsq.com

IEEE PES Transmission and Distribution Conference and Exposition
May 21-24, 2006
Dallas, TX
http://www.ieeet-d.org

Renewable Energy 2006
International Joint Conference with the International Solar Energy Society
October 9-13, 2006
Makuhari Messe, Chiba, Japan
http://www2.convention.co.jp/re2006/eng-conf

Web Sites

DOE Carbon Sequestration http://fossil.energy.gov/programs/sequestration

NETL Carbon Sequestration http://www.netl.doe.gov/technologies/carbon_seq
The National Energy Technology Laboratory is devoted to fossil energy research and technology.

Chicago Climate Exchange http://www.chicagoclimatex.com
The first US voluntary pilot program for trading of greenhouse gases.

Carbon Dioxide Information Analysis Center http://cdiac.esd.ornl.gov
CDIAC is the primary global change data and information analysis center of the DOE.

Carbon Mitigation Initiative http://www.princeton.edu/~cmi
A joint project of Princeton University, BP, and the Ford Motor Company.

Stanford University Global Climate and Energy Project http://gcep.stanford.edu
A collaboration aimed at developing energy systems with lower greenhouse gas emissions.

www.lanl.gov/energy

Energy Security
Los Alamos National Laboratory
P.O. Box 1663
Mail Stop C331
Los Alamos, NM 87545

Nonprofit
Organization
U.S. Postage
PAID
Albuquerque, NM
Permit No. 532